

ROSAT

(NASA-TM-104958) ROSAT: AN INTERNATIONAL
MISSION EXPLORING THE HIGH ENERGY UNIVERSE
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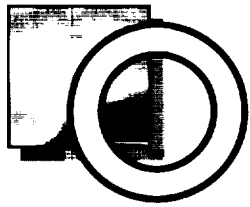
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AN
INTERNATIONAL
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EXPLORING
THE





OVERVIEW

**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**



MAPPING AND STUDYING A UNIVERSE INVISIBLE TO THE HUMAN EYE

Whether curiosity or fascination first prompted man to study the heavens, unsatiated, he has continued through the centuries to probe cosmic puzzles using instruments born of his imagination. One of these instruments, the "Roentgensatellit," known as ROSAT, rode into orbit atop a Delta-II rocket on June 1, 1990. Designed specifically to detect high-energy radiation, ROSAT's telescopes are investigating X-ray and ultraviolet emissions, regions of the electromagnetic spectrum that cannot be seen and that cannot penetrate the Earth's atmosphere.

Named for German scientist Wilhelm Conrad Roentgen, who discovered X rays in 1895, ROSAT began as a na-

tional space program in the Federal Republic of Germany. It grew into an international astronomical observatory project with the involvement of the United Kingdom and the United States.

ROSAT's science mission is divided into two phases. With its in-orbit check-out period complete, ROSAT has begun phase one of its mission, an all-sky survey to map the heavens. When the 6-month mapping survey is complete, the satellite will begin phase two and be pointed at selected objects, studying individual targets, for the remainder of its mission. All three participating countries have invited potential Guest Observers to submit proposals for in-

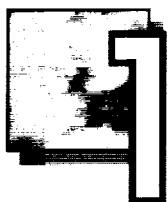
vestigations to be conducted during ROSAT's pointed phase.

In the United States, an extensive Guest Observer program is underway. Through the program, ROSAT's X-ray observing time will be shared by scientists from the United States and throughout the world. NASA supports the Guest Observers with two staffed facilities and with special software to aid in the analysis of data. In addition, an on-line data base provides updates on ROSAT's status and information needed to prepare proposals for additional pointed investigations.

With ROSAT, mankind continues its attempt to understand the energetics of processes at work in the universe. The discoveries of ROSAT are expected to raise new questions to be investigated by observations of the next generation of X-ray satellites.

**ORIGINAL PAGE
COLOR PHOTOGRAPH**

C CONTENTS



A NEW AGE OF ASTRONOMY

.....page 2



ROSAT'S HIGHLY SENSITIVE INSTRUMENTS

.....page 12



A HISTORY OF X-RAY ASTRONOMY

.....page 3



PROGRAM FOR GUEST OBSERVERS

.....page 16



SCIENTIFIC POTENTIAL OF ROSAT

.....page 5



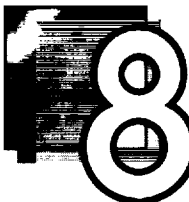
ROSAT MILESTONES

.....page 18



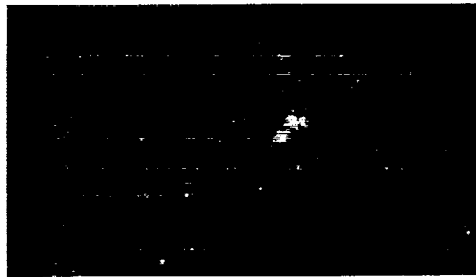
ROSAT'S MISSION IN A NEW DECADE OF DISCOVERY

.....page 9



ORGANIZATION

.....page 18



Eta Carinae is a massive star in the midst of a nebula of jewel-bright clouds and serpentine dust lanes (on the left as imaged in X rays, and on the right from an optical telescope). Since it was first observed in 1677, its brightness has waxed to first-magnitude brilliance, and waned to naked-eye invisibility. Scientists cannot agree on whether Eta Carinae is a dying star preparing to explode in a supernova, an exceptional nova, or an unusual binary.

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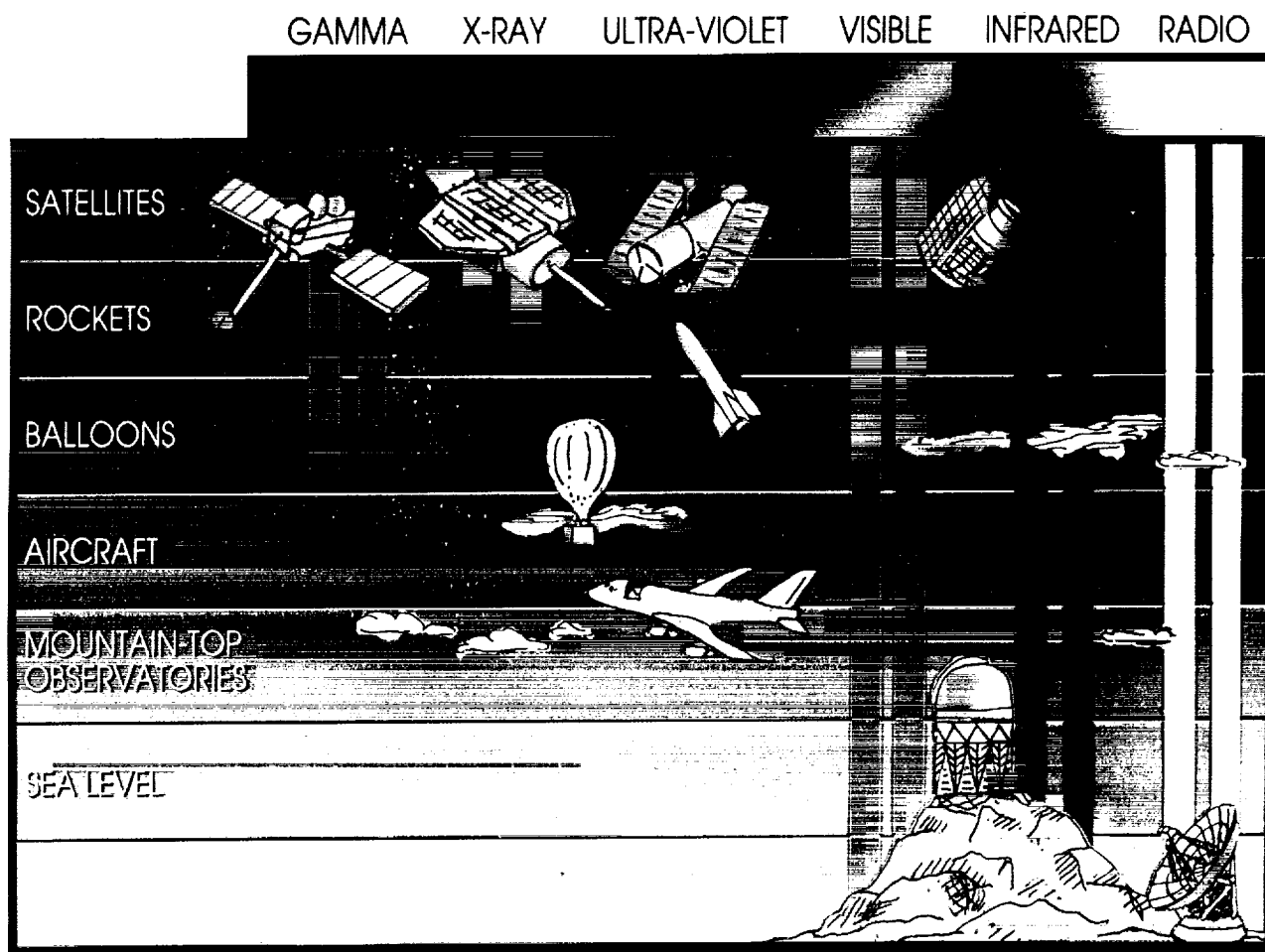
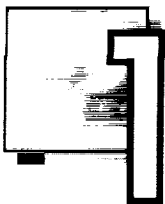


Wilhelm Conrad Roentgen (1845-1923)

A scientist with active curiosity, Wilhelm Conrad Roentgen discovered X-rays by chance. While trying to understand the cause of luminescence in a Crookes tube (the forerunner of the cathode ray tube), Roentgen covered one end of the tube to ensure that no light could escape. When he turned on the tube, a nearby screen that had been coated with fluorescent material began to glow. He knew that the glow was not caused by cathode-ray electrons. Cathode rays couldn't penetrate the black cardboard he had placed at the end of the tube. His curiosity piqued, Roentgen interrupted his study of cathode rays to learn about the radiation he called "X."

Roentgen's discovery was serendipitous—a matter of good luck—but as Louis Pasteur once said, "Chance favors only the mind that is prepared." Other scientists had noticed the fluorescent glow while using Crookes tubes, but they did not associate it with a new form of radiation. Roentgen later explained, "I didn't observe, I investigated."

Like the scientist for whom it is named, ROSAT is prepared for serendipitous discovery. With its enhanced observing and all-sky survey capabilities, ROSAT is well positioned to discover the unexpected.



Scientists use different means to get above Earth's obscuring atmosphere to study the full spectrum of electromagnetic radiation.

A NEW AGE OF ASTRONOMY

Stargazing has entered a new age — an age of space astronomy. For centuries, astronomical observations were limited to what could be seen with the naked eye and the visible light captured in Earthbound telescopes. Now, by placing instruments above the obscuring atmosphere, astronomers can scan the heavens across the entire electromagnetic spectrum to answer questions about the cosmos.

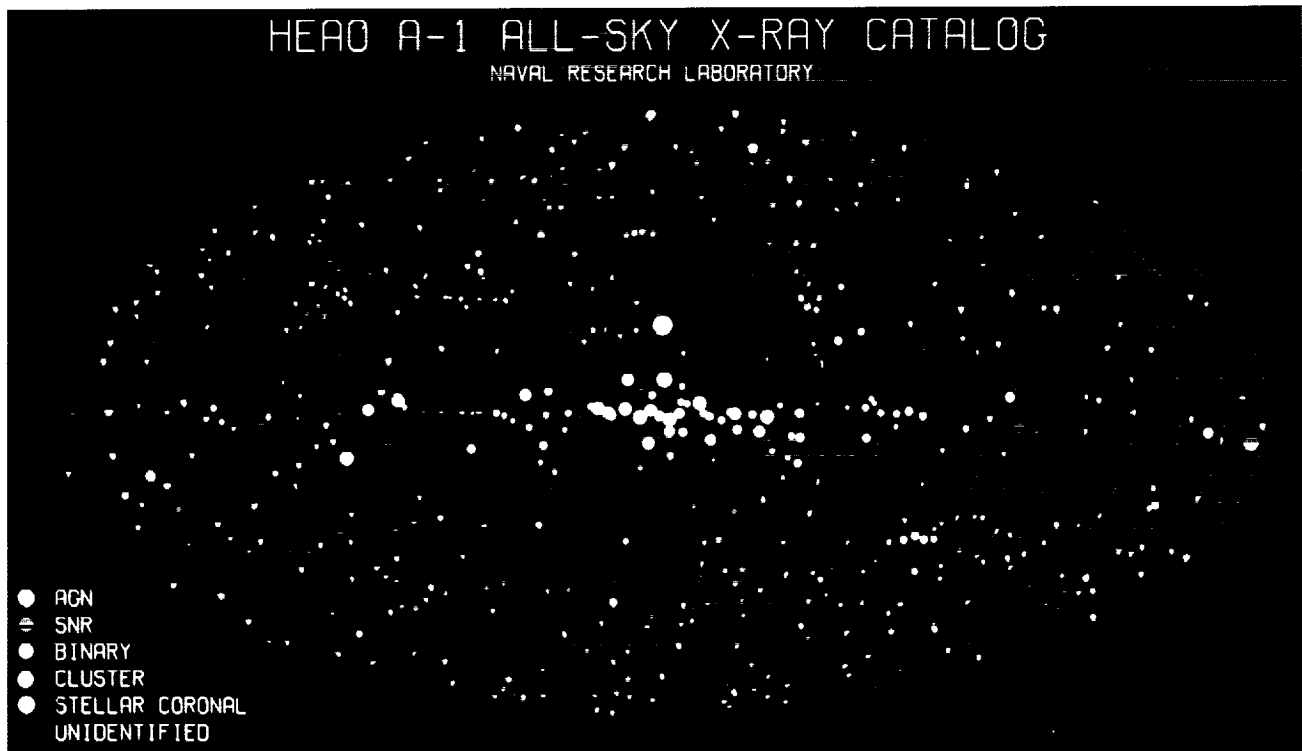
Light visible to the human eye represents only a fraction of the electromagnetic radiation emitted by objects throughout the universe. The new as-

tronomy has scientists investigating old mysteries with new “eyes” — instruments that view the universe in the electromagnetic wavelengths outside the visible band of the spectrum, emissions that do not penetrate to the Earth’s surface.

Just as visible light passing through a prism is dispersed into a rainbow of colors determined by their wavelengths, the invisible part of the electromagnetic spectrum can also be separated into differing bands of wavelengths. These range from very long radio wavelengths to extremely short gamma-ray wavelengths. The emission of X rays from

astrophysical objects indicates the presence of high-energy phenomena in the universe. The X rays may originate in very hot gases, or plasmas, with temperatures of several million degrees Kelvin (K). Alternatively, they may be produced by the interactions of streams of highly energetic particles with other particles or magnetic fields. Ultraviolet emissions are produced at somewhat cooler temperatures ranging from 10,000 to 100,000 degrees K.

When instruments that sense these various emissions were turned to the heavens, scientists discovered a previously invisible aspect of the universe.



A HISTORY OF X-RAY ASTRONOMY

The observation of high-energy radiation depends upon the ability to send detectors above Earth's atmosphere because it blocks such radiation. The study of celestial objects that emit X-ray, gamma-ray, and ultraviolet radiation only became possible with the advent of the space age.

In 1962, the science of X-ray astronomy was born with the flight of a small Aerobee rocket launched from White Sands, New Mexico. A team of scientists sent aloft a payload of three Geiger counters to investigate whether celestial sources other than the Sun also emitted X rays. The instruments recorded an unexpected, brilliant source of X rays located in the constellation Scorpius, later dubbed Sco X-1.

During the next 8 years, instruments launched on rockets and balloons detected several dozen bright X-ray sources in the Milky Way Galaxy and a few sources in other galaxies. The excitement over X-ray astronomy was growing and, in 1970, NASA launched the first satellite devoted to X-ray astronomy, the first Small Astronomy Satellite (SAS-1).

Also known as "Uhuru" (Swahili for freedom), SAS-1's task was to perform the first survey of the X-ray sky from which a catalog of X-ray sources could be developed. Uhuru discovered several hundred sources. They included binary star systems—systems in which two stars travel in tandem, revolving around one another; supernova rem-

nants — the remains of stars that have exploded violently; the nearby Andromeda Galaxy — a galaxy similar to the Milky Way; and several galaxy clusters — large gravitationally-bound groupings of galaxies.

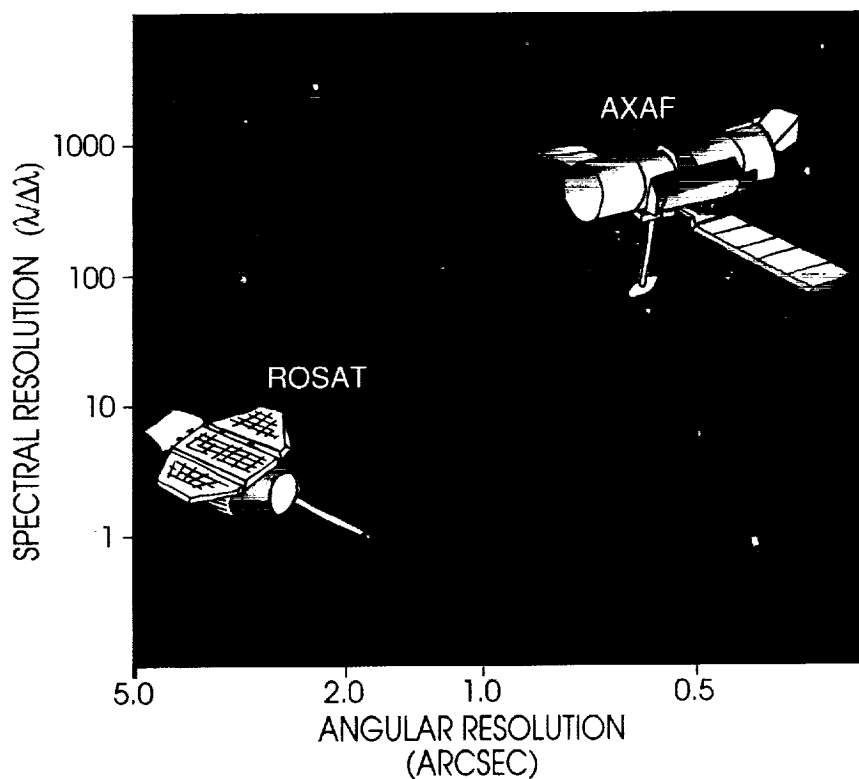
During the next 7 years, X-ray sources were studied by instruments on several satellites: among them a small X-ray telescope aboard NASA's Copernicus, two of NASA's Orbiting Solar Observatory satellites, the Defense Department's Vela 5-A, the Astronomical Netherlands Satellite, the British Ariel 5, and NASA's SAS-3. In addition, a vigorous program of rocket and balloon experiments was continued.

Numerous discoveries are credited to these early explorations: binary X-ray pulsars — a neutron star orbiting a normal companion and creating an X-ray emission that appears to wink on and off; X-ray bursters — compact objects that suddenly increase in intensity and then fade; X-ray emission from active stars; and active galaxies where the central regions (known as active galactic nuclei) emit huge amounts of X rays. Among the latter are “radio” galaxies, known for producing strong radio waves; “Seyfert” galaxies, named for their discoverer Carl Seyfert and known for intense levels of energy emanating from small central regions; and quasars, the most luminous objects in the universe, radiating up to a thousand times as much energy as the Milky Way Galaxy from an area no larger than the solar system.

In addition to a wide variety of discrete sources, these early experiments detected the presence of an isotropic X-ray background radiation arriving from all directions, the origin of which was a subject of intense speculation. A fraction of the observed sources, due to their X-ray faintness, distance, or the faintness of their optical counterparts, remained unidentified with any known astronomical objects.

In 1977, NASA launched its first large orbiting X-ray observatory, HEAO-1, one in a series of three High-Energy Astronomy Observatory satellites. Weighing 3.5 tons, HEAO-1 carried into orbit four experiments that surveyed the sky and pinpointed sources of X-ray and gamma-ray emission but had no capability of producing images of emitting objects. The observatory conducted a sky survey, increasing the number of cataloged X-ray sources to approximately 1,500.

Accomplishments credited to HEAO-1 are many: the first precise measure-



ROSAT is an evolutionary step along the way to the Advanced X-Ray Astrophysics Facility (AXAF), NASA's "Great Observatory" for X-ray observations beginning in the late 1990s. AXAF will provide major advances in spectral and angular resolution, as well as increased sensitivity and energy response.

ment of the energy spectrum of the diffuse X-ray background radiation, implying a possible origin in a universal hot plasma; a very large bubble of hot gas in the constellation Cygnus stretching across more than 1,000 light years of space and containing the mass of several hundred thousand Suns; a new black hole candidate; and the discovery that the class of objects known as active galactic nuclei are powerful sources of X rays. HEAO-1 remained in operation until early 1979.

Until the launch of the second High Energy Astronomy Observatory in 1978, scientists studied X-ray sources primarily by determining their positions, measuring their X-ray spectra, and monitoring changes in their X-ray brightness over time. With HEAO-2 (known as the Einstein Observatory), it became possible to routinely produce images of cosmic X-ray sources rather than to simply locate their positions. The Einstein Observatory was the first imaging X-ray telescope to be deployed in Earth orbit. With it, as-

tronomers obtained X-ray images of such extended optical objects as supernova remnants, normal galaxies, clusters of galaxies, and active galactic nuclei. Einstein observations revealed that all classes of objects known to classical optical astronomy were also sources of X rays. Among the Einstein Observatory's most unexpected discoveries was that all stars, from the coolest to the very hottest, emit significant amounts of X rays.

Thousands of cosmic X-ray sources became known after discoveries from NASA's Einstein Observatory and the European Space Agency's EXOSAT Observatory (launched in 1983) were added to the X-ray catalog. Astronomers now recognize that a significant fraction of the radiation emitted by virtually every type of object in the cosmos emerges as X rays. Each succeeding X-ray mission has made discoveries at the limit of its capability and has tantalized astronomers to push on to higher capabilities of resolution and sensitivity.

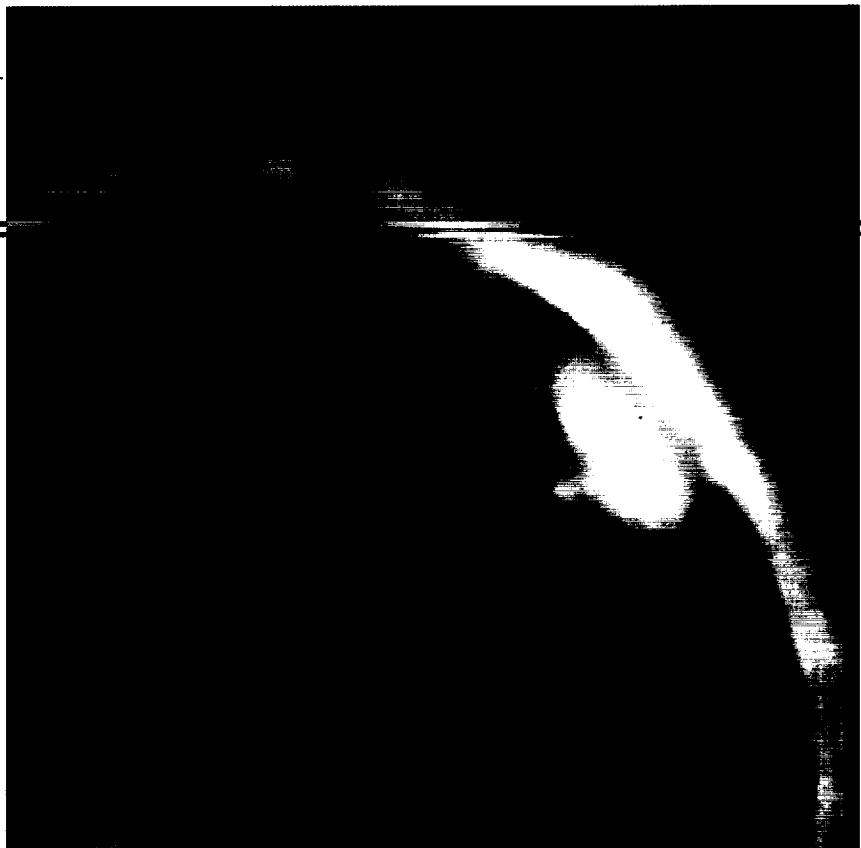
SCIENTIFIC POTENTIAL OF ROSAT

A myriad of unsolved questions awaits investigation by ROSAT. The observatory's unique capabilities will provide high-resolution imaging of objects with a precision and sensitivity that match or exceed those of previous observations.

Normal Stars — Normal stars are excellent candidates for ROSAT observations. While all classes of stars have been found to emit X rays at some level, different types of stars apparently emit X rays via several different mechanisms.

Cool stars, like the Sun, are known sources of X rays that originate in a layer above the visible photosphere. The Sun's outermost layer seethes with an intensely hot, low density gas that creates a stellar corona, or crown, which is visible when the brilliant photosphere is masked out, as in an eclipse. X rays are thought to be produced in a stellar corona by the dynamo action of a star's magnetic field in which turbulent motion of the field heats gases to a million degrees K or more. The Sun will not be observed with ROSAT because it would burn out the sensitive instruments designed to observe very faint nonsolar X-ray sources. However, ROSAT will add to astronomers' knowledge of the stellar corona phenomenon by extending the study of coronae in other cool stars to a very large sample.

In hot stars, those which are 5 or 10 times hotter than the Sun and 10 to 100 times more massive, scientists believe stellar winds carry shock-heated blobs of gas that emit X rays. For observations of this emission, the less massive sources should prove the most informative because of the absence of dense stellar winds that absorb X rays. Many such objects are expected to be detectable for the first time with ROSAT.



The corona of the Sun surrounds the solar photosphere like a halo in this photo. Although ROSAT cannot turn its delicate instruments toward the Sun, it will study coronae in many other stars.

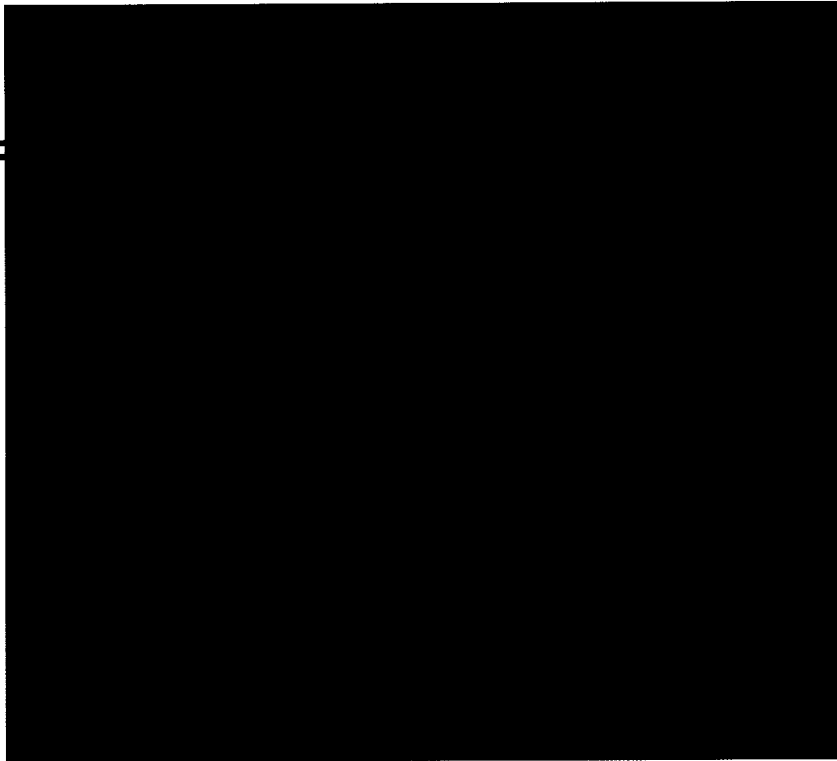
Very young stars also exhibit substantial X-ray emission, although the origin of this radiation remains largely a mystery. Stars are born in incubators of collapsing gas and dust called molecular clouds, which often prevent the escape of X rays from their cores. As a molecular cloud collapses, temperatures climb and nuclear reactions begin; from this protostar, a star bursts to life. ROSAT's sensitivity may allow observation of these heavily obscured objects.

Supernova Remnants — A pool of expanding supernova remnants has disrupted and enriched the interstellar medium since shortly after the birth of the Milky Way Galaxy. In the process of a massive star collapsing into a neutron star or black hole, much of its mass is expelled in a violent explosion known as a supernova. X-ray studies of the expanding stellar remnant produced by the explosion tell us much about the progenitor star, its evolution, and the nature of the surrounding interstellar medium.

Scientists hope the high resolution of ROSAT will be able to reveal structural details of supernova remnants, adding to their understanding of remnant evolution.

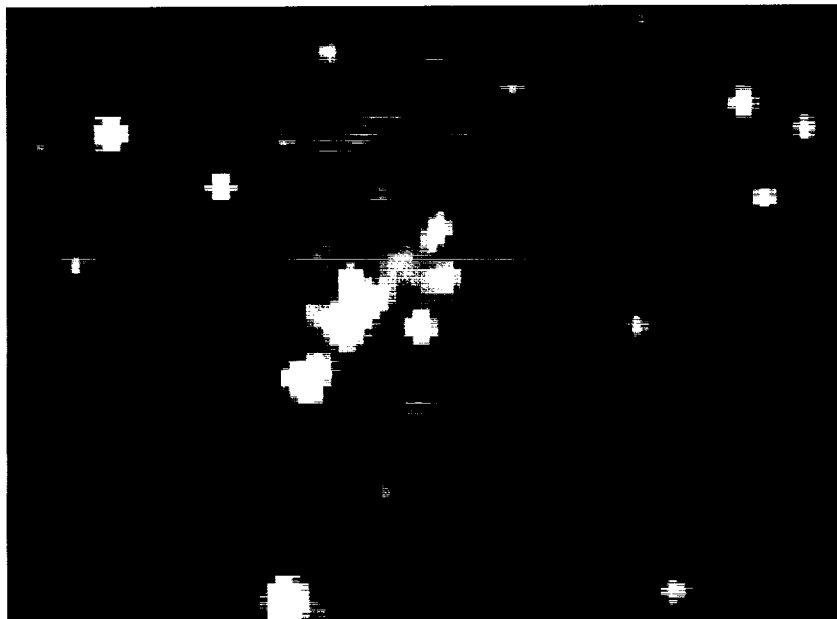
Compact Objects — Reacting to the exhaustion of its nuclear fuel supply and the inexorable forces of gravity, a star of mass greater than that of the Sun will eventually collapse. Depending upon the star's exact mass, it will become either a white dwarf (approximately the size of the Earth), a neutron star (no larger than 10 kilometers in radius), or a black hole - a massive object so compact and with gravity so great that not even light can escape it. The X-ray emission from the hot gas surrounding and falling onto such compact objects is a key to their detection and study.

Accurate positions can be obtained by ROSAT for several known compact X-ray sources for which positional data have been poorly defined. Identification of these sources with optical objects will provide a critical tool in de-



SNR E0102.2-72.2 in X rays

This supernova remnant in the Small Magellanic Cloud was discovered by the Einstein Observatory. Observations carried out at optical wavelengths soon after the discovery revealed strong emission lines of oxygen and neon and very little emission from other elements. From an estimated velocity of expansion and its linear size, it is inferred that this remnant is between 1,000 and 2,000 years old. The X-ray image shows emission from a clumpy ring of ejected gas and dust particles. With ROSAT, scientists hope to study the ring-like nature of the emission in more detail.



Optical image of SNR E0102.2 72

Understanding the relationship between the optical and X-ray emission components and why they appear so different from one another should reveal interesting aspects of the physics of shocks in supernova remnants.

termining the nature of their basic physical parameters.

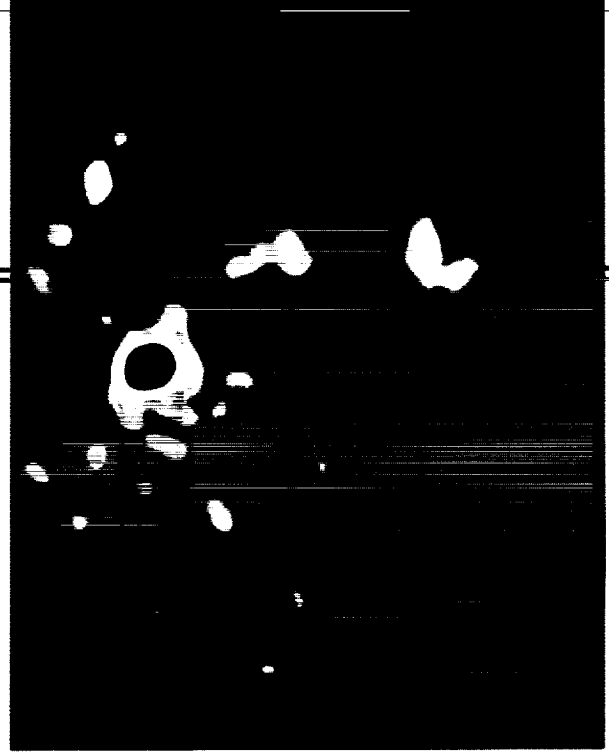
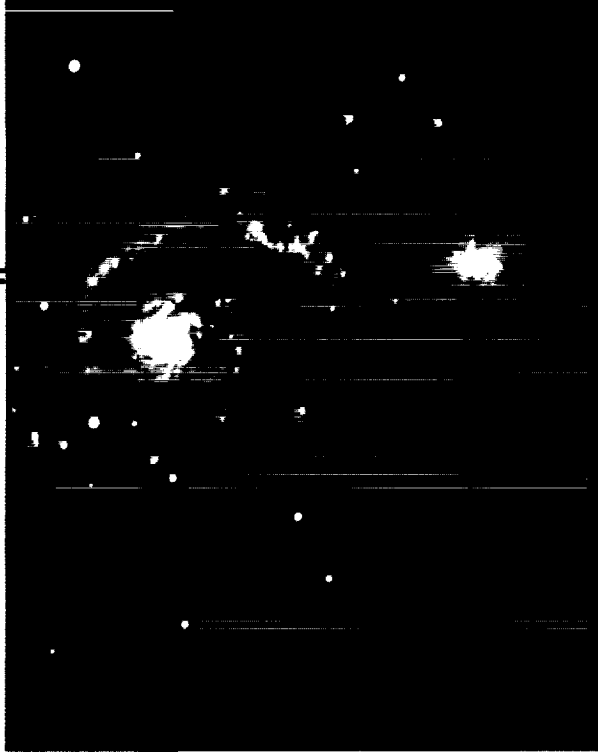
X-Ray Binaries — A majority of stars travel in pairs, revolving around one another in binary systems. In X-ray binaries, where the compact star is attracting a flow of X-ray emitting gas from its companion, analyses of X-ray flux variations help define the emitting regions. Such analyses are particularly useful in identifying an eclipsing binary system, where a nonemitting companion acts as a shutter being drawn across the emitting region. Observing the eclipse helps to establish the shape and size of the region and reveal the physical processes at work.

Beyond the Milky Way Galaxy, a seemingly infinite number of other galaxies, either isolated in space or members of clusters, are available for study by ROSAT.

Galaxies — Normal galaxies are known to be sources of X rays, but because they tend to be less X-ray active than other extragalactic objects, they have been difficult to study. Normal galaxies are generally divided into two classes: *spiral galaxies*, which are flattened disks of gas, dust, and stars, often with bar or spiral-arm patterns; and *elliptical galaxies*, which are spheroidal systems of stars that are usually more massive than spirals.

The predominant X-ray emission mechanisms differ in spiral and elliptical galaxies. In spirals, the X rays that are detected represent the combined emission from many individual sources, such as X-ray binaries and supernova remnants. ROSAT, with its improved sensitivity and resolution, will allow detection of these individual sources in many galaxies.

Dark Matter — In contrast to the emission from spiral galaxies, X rays from elliptical galaxies appear to



The spiral galaxy M51, also known as the Whirlpool Galaxy, is actually two interacting galaxies approximately 35 million light years from Earth. The left view of the galaxy is from an optical telescope; the right view shows the Whirlpool as seen in X rays by instruments on the Einstein Observatory.

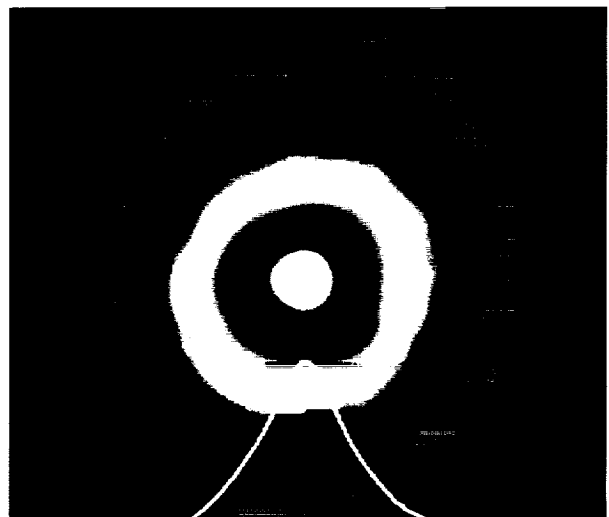
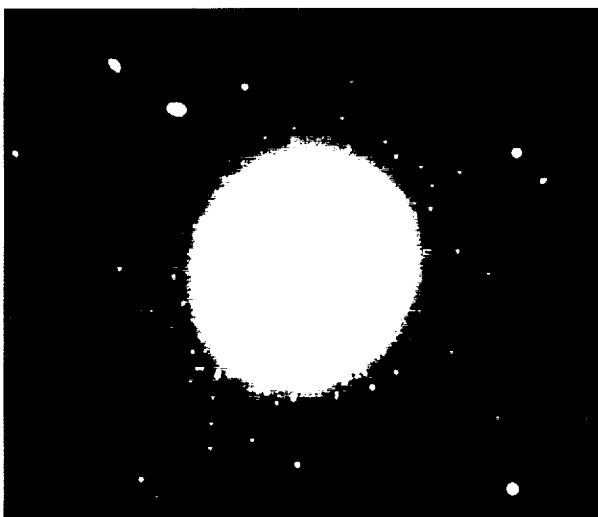
originate in a diffuse gas that is heated to several million degrees K and is gravitationally bound to the galaxy. This gas is of particular interest because it provides information on nonluminous material, the so-called "dark matter," that may be present in a galaxy. Because the gas is bound by gravity, a knowledge of the gas's density and temperature will enable scientists to estimate the total mass of the galaxy. The difference between this total mass and that fraction observed in the form of luminous stars and X-ray emitting gas

represents the amount of dark matter associated with the galaxy.

Invisible to optical telescopes, dark matter therefore contributes a gravitational force that cannot be accounted for by luminous matter. The presence of dark matter in several galaxies, as implied by X-ray observations, was initially established by the Einstein Observatory. The greater sensitivity, spatial resolution, and spectral resolution of ROSAT will increase the sample of galaxies studied and provide a more

precise determination of the total mass and distribution of dark matter in elliptical galaxies.

Active Galactic Nuclei (AGNs) — In addition to the more common spiral and elliptical galaxies, a small fraction of galaxies release very large amounts of energy from highly compact regions inside their nuclei. These so-called active galactic nuclei (AGNs) release more energy than can be accounted for by the stars contained within the galaxies. A well-known class of AGN is the



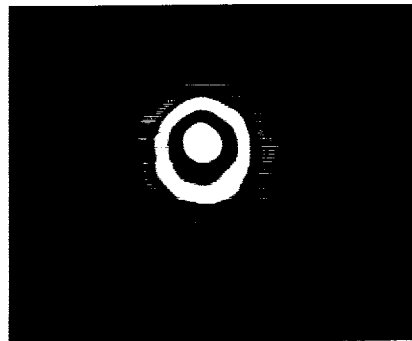
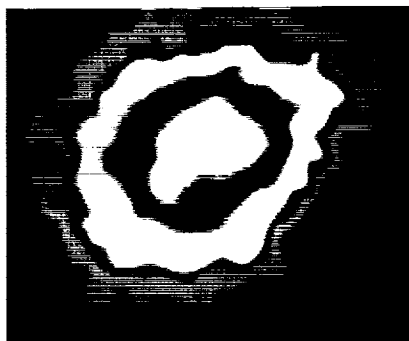
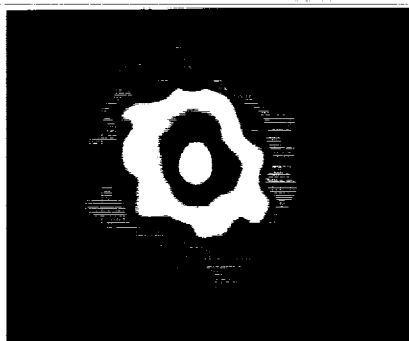
M87, an elliptical galaxy in the Virgo cluster of galaxies, seems unremarkable in the optical view on the left. X rays, however, reveal gases at a temperature of 30 million degrees stretching across half a million light years. In order to retain this high-temperature gas by gravitational attraction, M87 must have a mass billions of times that of the Sun.

quasi-stellar object, or "quasar." The most luminous objects in the universe, quasars are also the most distant objects ever observed. How such objects radiate more power than the entire Milky Way Galaxy from an area smaller than the solar system is one of the most challenging questions of present-day astrophysics.

The high luminosities of AGNs suggest that they may be powered by the release of gravitational energy as matter is accreted, or accumulated, onto a compact massive central object, such as a black hole. Current ideas favor the formation of a disk of matter, heated by friction as material is pulled inward by gravity, accreting onto the central object. A large fraction of the energy emitted by AGNs is in the soft X-ray band, — the X-ray band closest to the ultraviolet region of the spectrum. ROSAT, with its unprecedented soft X-ray sensitivity, is well equipped to help scientists understand these energetic objects.

Galaxy Clusters — Clusters of galaxies, in which many galaxies are gravitationally bound together, represent another area of study for ROSAT. Early X-ray astronomy experiments discovered these clusters to be copious sources of X-ray emission, now known to originate in hot (multimillion degree K) gas permeating each cluster. The mass of this gas is usually comparable to or greater than that of the galaxies that can be seen in visible light. The total mass of a cluster — including member galaxies, the X-ray emitting gas, and any "dark matter" — can be estimated by using X-ray observations in the same way as for elliptical galaxies. ROSAT will be especially effective for observing the lower-temperature clusters that radiate predominantly in the soft X-ray region.

Diffuse X-Ray Background — In addition to discrete sources of X rays,



Clusters of galaxies as observed with the Einstein Observatory

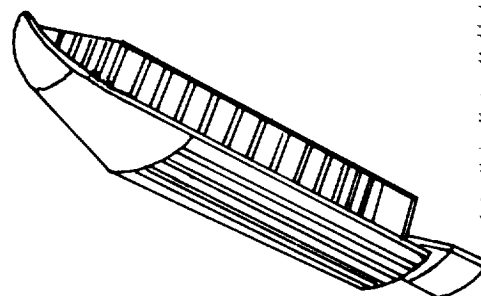
the existence of an apparently uniform and isotropic X-ray glow, called the diffuse X-ray background, has been known since the earliest rocket experiments. Although this radiation has been extensively studied, its source remains a subject of debate.

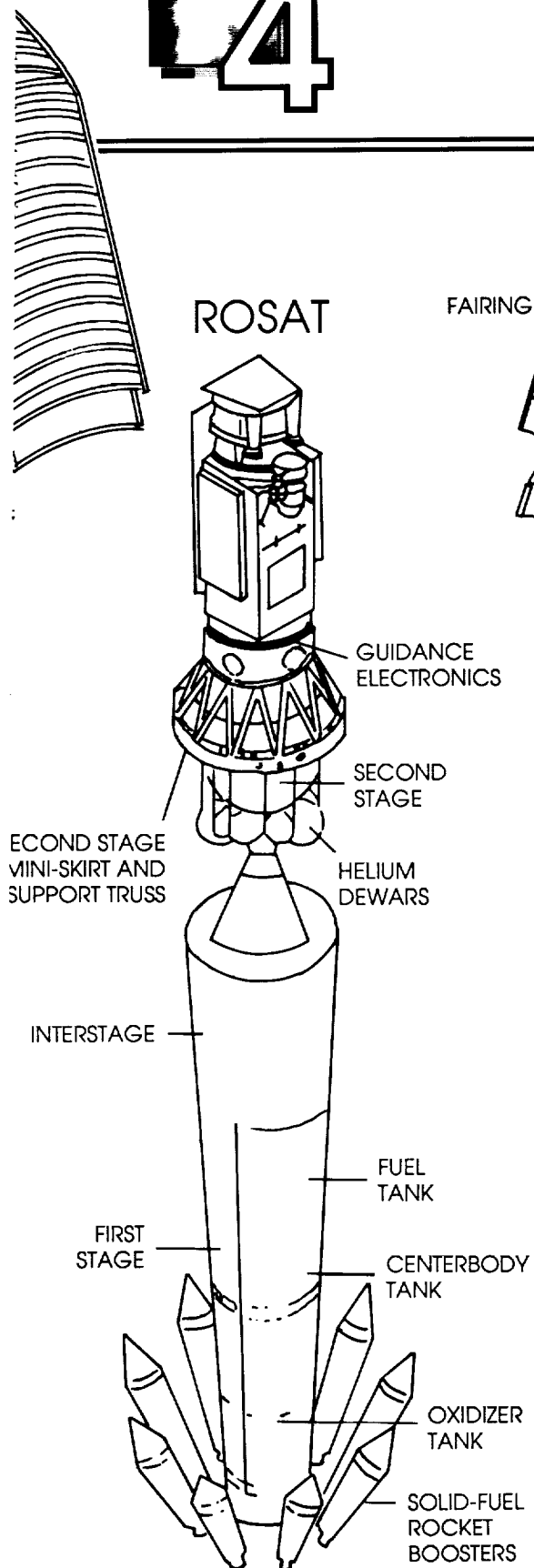
Two possible origins for the X-ray background have been proposed: an intergalactic hot gas, more or less smoothly distributed throughout the universe; or the combined emission from a large number of discrete sources too numerous and weak to be individually detected by past instruments. A strong constraint on a possible diffuse source origin for the background was recently provided by results from experiments on NASA's Cosmic Background Explorer (COBE), which indicate that any such hot gas would have to be highly clumped and not uniformly distributed. A number of candidates for the underlying source population in the discrete-

source theory of the X-ray background have been proposed, including such possibilities as starburst galaxies, active galactic nuclei, quasars, or a class of objects not yet known.

ROSAT's enhanced sensitivity and spatial resolution can be used to help determine the origin of the diffuse X-ray background, by making deep exposures of selected sky regions otherwise devoid of known sources. ROSAT will attempt to detect and resolve the individual objects that may be contributing to the diffuse background.

By virtue of its enhanced capabilities for observing the X-ray characteristics of a wide range of astrophysical objects and processes, ROSAT offers astronomers a new window on the universe. Each new observation holds the potential for discovery. Each new discovery holds the promise of solving a cosmic mystery and providing a clearer picture of the universe.





The Delta-II vehicle configuration for ROSAT

ROSAT'S MISSION IN A NEW DECADE OF DISCOVERY

Mankind's understanding of the origin and fate of the universe and the birth, nature, and evolution of the objects within it is expected to increase greatly during the decade of the 1990s.

Scientists will be studying celestial objects across the entire electromagnetic spectrum with several major space observatories scheduled for launch during this decade: the Hubble Space Telescope (HST), already in orbit, for visible, infrared, and ultraviolet wavelengths; the Gamma Ray Observatory (GRO) for gamma rays; the Advanced X-Ray Astrophysics Facility (AXAF) for X rays; and the Space Infrared Telescope Facility (SIRTF) for infrared radiation.

In the investigation of X-ray sources, ROSAT will follow the path set by HEAO-2 (the Einstein Observatory) and will be a key link in preparing for AXAF observations. ROSAT contributes to this evolution in instrument capability with its enhanced sensitivity, resolution, and completeness of sky coverage. ROSAT has a sensitivity five times greater and angular resolution (capability to separate adjacent sources) three times greater than HEAO-2, which was the most sensitive X-ray observatory previously flown.

For the United States, ROSAT's specific mission is to advance the science of astrophysics through the study of X-ray emission from nonsolar celestial objects. This will be realized primarily through the pointed phase studies of selected sources and, to a lesser extent, through limited participation in the X-ray all-sky survey.

ROSAT also carries a Wide-Field Camera, which will extend the satellite's coverage of celestial phenomena to extreme ultraviolet wavelengths, 300 to 60 angstroms (0.042 to 0.21 kilo electron Volts, or keV). This camera, developed and supplied by the United Kingdom, will provide the first survey of the sky in this little-studied region of the electromagnetic spectrum.

Objects to be studied during ROSAT's pointed phase are being selected by the international astrophysics community through proposals to a Guest Observer program. Proposals for the first 6 months of pointed observations were invited in 1989. Additional calls for proposals will take place during the lifetime of ROSAT.

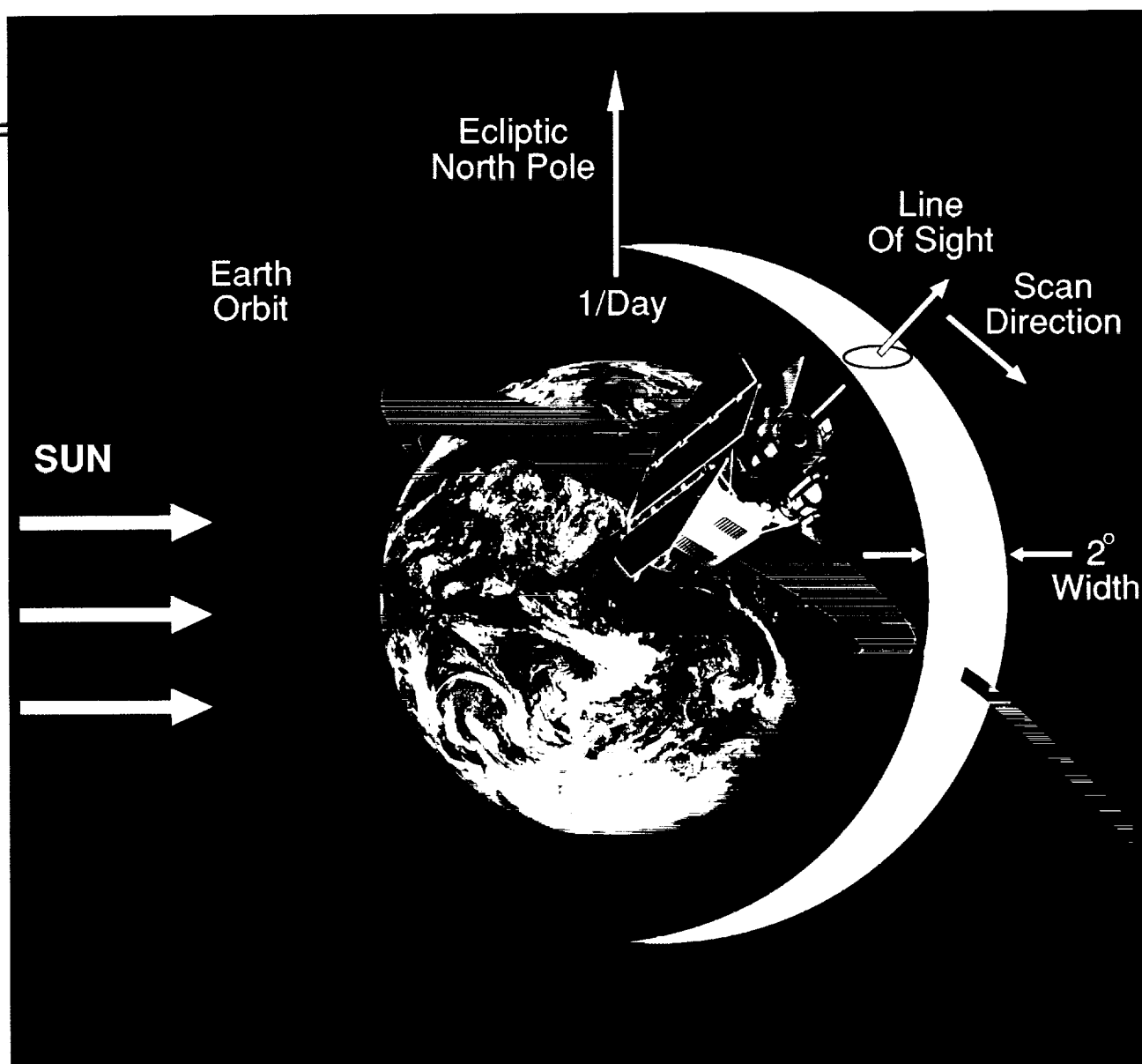
ROSAT was launched into orbit aboard a two-stage Delta-II launch vehicle from the Cape Canaveral Air Force Station in Florida by the US Air Force for NASA. The Delta II was augmented with a specially designed fairing to accommodate the ROSAT spacecraft. NASA assisted ROSAT operations by providing pre-launch testing support, Deep Space Network (DSN) support in the first weeks after spacecraft separation from the launch vehicle, and backup DSN support of the German ground tracking and data system, if needed, throughout the mission.

ROSAT's orbit is nearly circular, at an altitude of approximately 580 km and at an inclination to the Earth's equator of 53°, with an orbital period of 96.2 minutes. Designed to observe X rays in the range from 0.1 keV to 2 keV, commonly called the low-energy or soft X-ray band, the ROSAT telescope is so sensitive that it can detect and record X rays from all known classes of celestial sources.

During the all-sky survey, the X-ray telescope scans a band 2° wide during each revolution around the Earth, thus



*ROSAT traveled into orbit aboard a
Delta-II launch vehicle on June 1, 1990.
Inset: ROSAT during pre-launch
preparations.*



During the all-sky survey, ROSAT's telescopes will scan the celestial sphere in great circles as the satellite orbits the Earth.

completing the survey in 6 months. Scientists expect to locate more than 100,000 X-ray sources with a positional accuracy of approximately 30 arc seconds during the ROSAT sky survey.

In its second phase, ROSAT will be pointed at selected individual X-ray sources. Many X-ray sources are faint, and a typical ROSAT observation will require approximately 10,000 seconds (about 3 hours) to record an X-ray signal of adequate strength.

The German Space Operations Center (GSOC), located in Oberpfaffenhofen near Munich, operates the spacecraft

using the 15-meter antenna at the Deep Space Station near Weilheim, Germany. The spacecraft contacts the ground station on six consecutive orbits daily, for 6 to 8 minutes per contact. During periods when no communications are possible, commands are stored on the spacecraft and data are stored on one of two tape recorders. The tape recorders can hold 21 hours of data.

After telemetry capture at Weilheim, data are sent to the GSOC for a quality check and initial processing. Data are reformatted as necessary and transmitted for evaluation to the German ROSAT

Science Data Center at the Max Planck Institute for Extraterrestrial Physics (MPE) in Garching. The GSOC distributes Guest Observer data tapes to the ROSAT Science Data Centers in the three participating nations.

MPE processes and analyzes X-ray data acquired during the survey mode and is responsible for compiling an X-ray source catalog. The processing, distribution, analysis, and archiving of the data from the ultraviolet camera are the joint responsibility of the United Kingdom and the Federal Republic of Germany.

ROSAT'S HIGHLY SENSITIVE INSTRUMENTS

THE SATELLITE

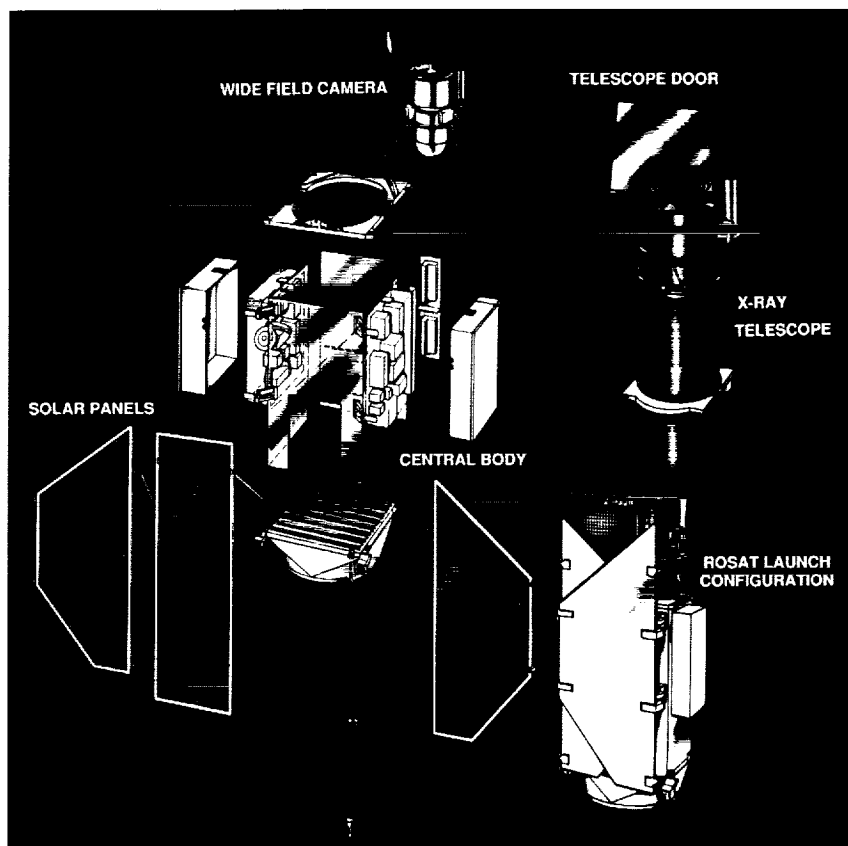
The design of the ROSAT spacecraft was driven by the structure of its X-ray telescope and Wide-Field Camera. Spacecraft support systems were built around the telescope assembly, which is nearly 4 meters (13 feet) long. The spacecraft, which weighs 2429 kilograms (5,354 pounds), has a square body with an adapter for the Delta-II rocket. An array of three solar panels provides 1,000 Watts of power to the spacecraft and science payload. The large, unobstructed rear surface of the array dissipates excess heat into space.

During launch, two of the solar panels were folded over the central body of the spacecraft. These were deployed on orbit, along with antenna masts. Protective telescope "doors" were then opened to permit the first observations.

Orbiting the Earth at 17,000 miles per hour, the satellite locates and locks onto targets using gyroscopes, Sun sensors, and magnetometers for coarse orientation information, and two star trackers for a highly accurate sky reference based on known star positions. A system of gyroscopes, reaction wheels (angular momentum flywheels), and magnetic torquing devices are used to maintain stable pointing at a selected target and to re-orient the spacecraft to point at a new target.

THE X-RAY TELESCOPE

In X-ray astronomy, each new project and advance in technology has led to new discoveries. ROSAT carries the finest high-resolution X-ray mirrors ever made. The ROSAT X-ray telescope's principal subsystems are its mirror as-



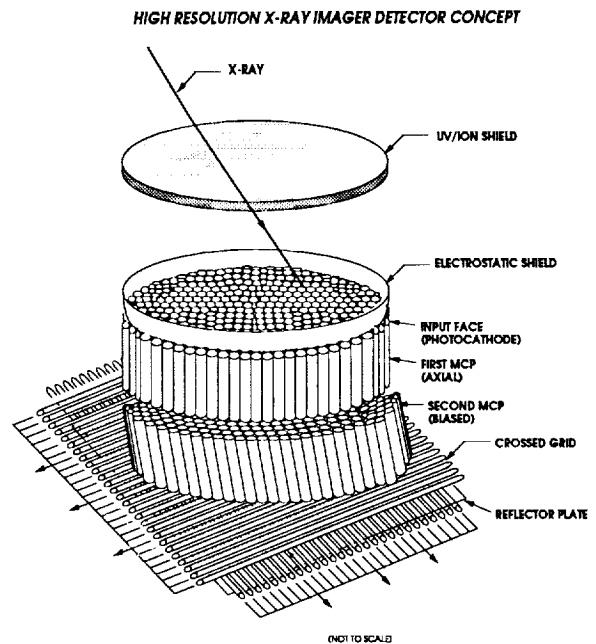
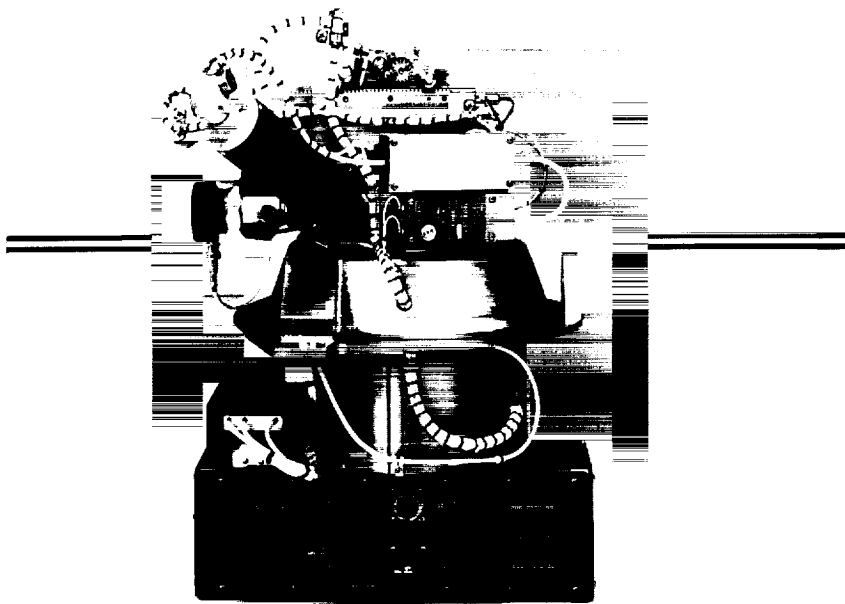
Flight model of ROSAT

sembly and its focal-plane detectors. Two Position-Sensitive Proportional Counters and a High-Resolution Imager are mounted on the turret in the focal-plane instrument section, where they can be used one at a time.

Because X rays interact more strongly with metallic surfaces than does visible light, a critical angle exists for the reflection of X-ray photons (particles of electromagnetic radiation). If the X ray strikes a mirror at an angle greater than the critical angle, it is absorbed and lost. To be reflected, it must strike the mirror surface at a grazing angle, hence the name "grazing incidence mirror." ROSAT uses four pairs of nested grazing incidence mirrors to provide the total reflecting area required for the

specified energy range. ROSAT's mirrors, known as a Wolter Type I configuration, consist of tubelike shells nested inside one another. Each shell contains a pair of hyperbolic and parabolic grazing incidence mirrors supported at one end by a central flange. All of the mirror shells are made of Zerodur, a glass ceramic, and coated with a thin layer of gold to increase X-ray reflectivity.

The ROSAT mirrors yield higher angular resolution and produce less scattering than any previous X-ray mirrors, thereby permitting greater image contrast. The X-ray mirror assembly is the product of a joint endeavor between Germany's Max Planck Institute for Extraterrestrial Physics (MPE) and the Carl Zeiss Corporation.



The High-Resolution Imager was provided by the Harvard-Smithsonian Center for Astrophysics.

HIGH-RESOLUTION IMAGER

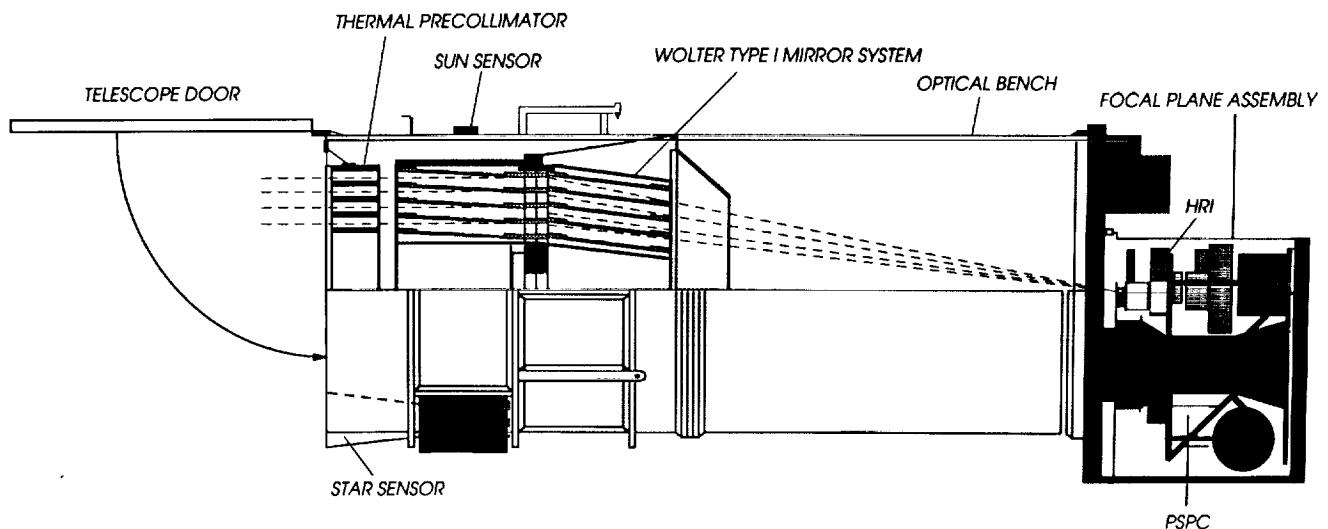
The ROSAT High-Resolution Imager (HRI), which was developed for NASA by the Harvard-Smithsonian Center for Astrophysics, is based upon a design flown successfully on the Einstein Observatory. Several modifications have been made to enhance the HRI's performance, including an increase in quantum efficiency and a reduction in the level of internal background.

While the HRI has spatial resolution superior to that of the Position-Sensitive Proportional Counters, it has very limited energy resolution and covers a

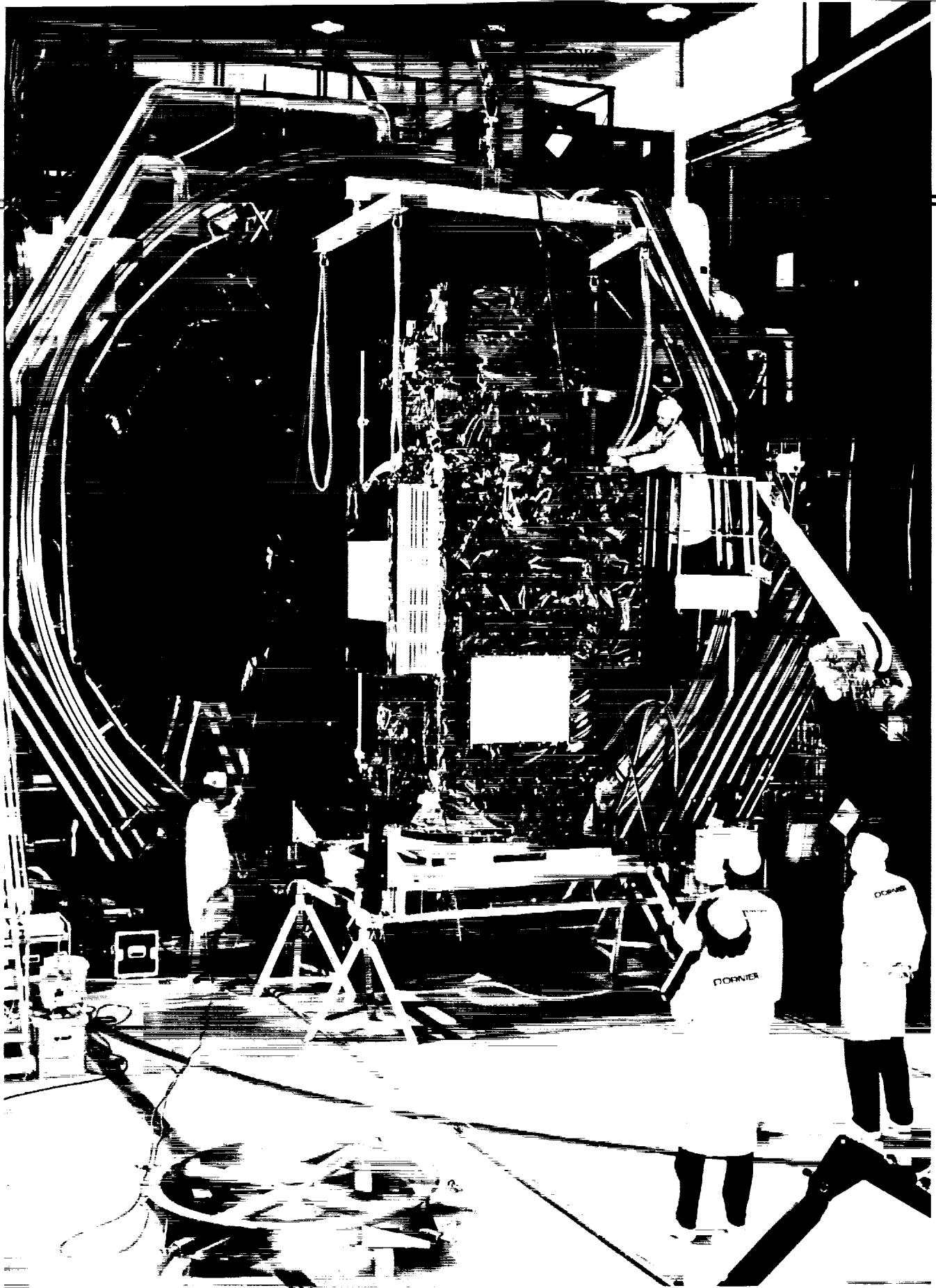
smaller field of view. Consequently, the HRI is better suited for precisely locating X-ray sources, for separating sources in regions where they are too close together for study by the proportional counters, and for resolving small-scale features of extended objects.

The detector consists of two microchannel plates in a cascade configuration, with a grid of crossed wires for electronic readout (see figure above). Microchannel plates absorb incident X rays and amplify the signal for position determination via the crossed-wire grid below the plate. Each microchannel

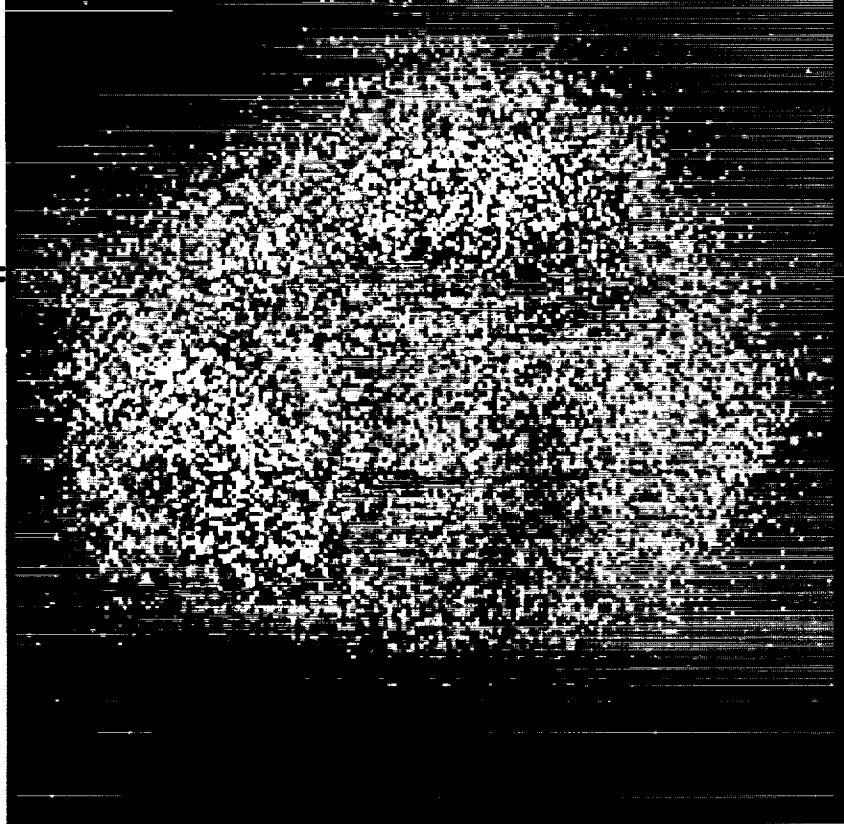
plate is an array of small hollow tubes or channels. An X-ray photon striking the surface of a channel frees an electron. The electric field produced by a high voltage applied across the microchannel plate accelerates this electron, which then collides with the wall of the tube to produce more electrons. A series of electrons thus cascades down the tube, multiplying in number until a sufficient signal is produced to be recorded electronically, revealing the location of the incident X-ray photon. The array of such events is used to produce the X-ray image of a given field.



A cross section of the ROSAT X-Ray telescope



Flight model of ROSAT at Dornier GmbH



This image of the Cassiopeia A supernova remnant was recorded during ROSAT's check-out period by one of the Position-Sensitive Proportional Counters.

POSITION-SENSITIVE PROPORTIONAL COUNTERS

The two Position-Sensitive Proportional Counters (PSPCs) on ROSAT are improved versions of those flown on sounding rockets by MPE. The PSPCs are a type of gas counter in which X rays are photoelectrically absorbed.

X rays enter the detector through its entrance window and interact with the gas inside. The photoelectrons produced by the interaction are accelerated; as they move through the gas, they produce more electrons. Planes of wires locate the electrical signals, recording the position and amplitude of each incoming X-ray photon event. The strength of the electronic signal is proportional to the energy of the incident X ray. The collection of all of the events from a given source provides its position and energy spectrum.

While these detectors do not resolve sources in space as accurately as the HRI, they cover a wider field of view and provide photon energy measurements not possible with the HRI.

WIDE-FIELD CAMERA

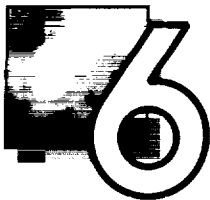
The Wide-Field Camera (WFC) was developed and supplied by a consortium of institutions in the United Kingdom led by the University of Leicester. Complementing the X-ray telescope,

the WFC extends ROSAT's spectral coverage into the extreme ultraviolet region, 0.042 to 0.21 keV.

The WFC functions as an autonomous instrument, with its own star tracker (for position information), thermal control system, and command and data handling system. Power, on-board data storage, command reception, and telemetry are provided by the spacecraft. Coaligned with the X-ray telescope, the WFC has a wider field of view (5° circular diameter). The optics consist of a nested set of three grazing - incidence mirrors, known as Wolter-Schwarzschild Type 1, fabricated from nickel-plated aluminum and coated with gold for optimum reflectance.

Two identical detector assemblies are mounted on a focal-plane turntable so that either one can be selected for use. A filter-wheel assembly containing eight spectral filters is located in front of the detectors. Any one of the filters may be chosen to select a specific energy band, depending on the target to be studied.

THE ROSAT OBSERVATORY			
	X-RAY TELESCOPE		WIDE-FIELD CAMERA
	POSITION-SENSITIVE PROPORTIONAL COUNTERS	HIGH-RESOLUTION IMAGER	
ENERGY RANGE	0.1 - 2 keV	0.1 - 2 keV	0.04 - 0.21 keV
ANGULAR RESOLUTION	10 arcsec (FWHM, at 1 keV)	5 arcsec (half energy width)	1.7 arcmin (half energy width at 0.04 keV)
ENERGY RESOLUTION	40% at 1 keV	none	
FIELD OF VIEW	circular, 2° diameter	32 arcsec	circular, 5° diameter



PROGRAM FOR GUEST OBSERVERS

Scientists around the world were invited to submit proposals for the objects to be studied by ROSAT during the first 6 months of the pointed phase. Half of the pointed observation time with the X-ray telescope will be devoted to observations conducted under the US Guest Observer Program, with the remaining 50 percent allotted to the corresponding programs of the Federal Republic of Germany and the United Kingdom.

Proposals for participation in the US Guest Observer Program are submitted to NASA Headquarters, where a two-stage process is followed:

- A scientific and technical evaluation directed by NASA is conducted by peer-review panels and by the US ROSAT Science Data Center (RSDC) staff to assess feasibility. All feasible proposals are prioritized according to scientific merit.

Final selection of US proposals is made by the Director of the NASA Astrophysics Division.

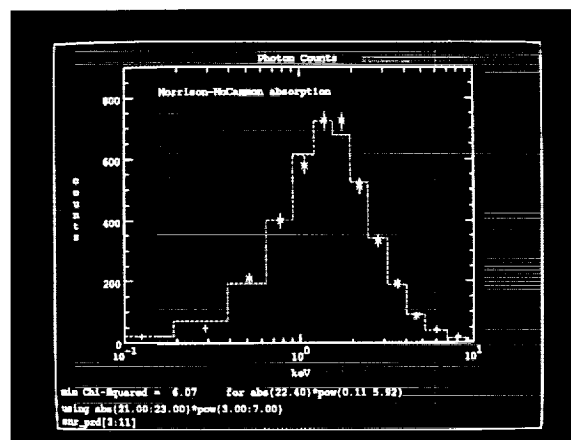
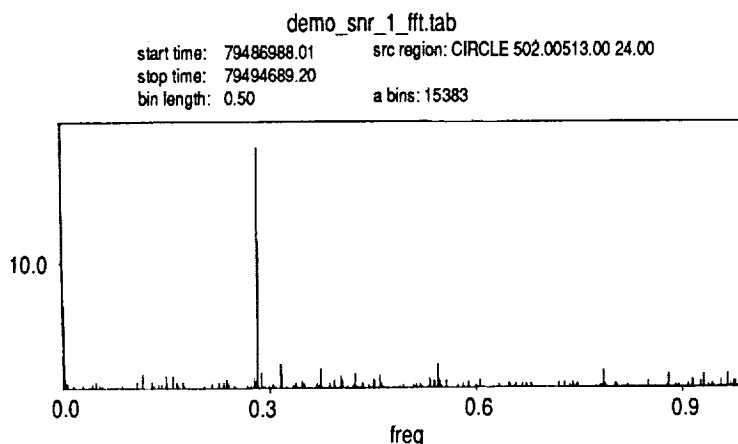
- The International ROSAT Users' Committee, made up of representatives from the three participating countries and chaired by the FRG's Project Scientist, meets to resolve duplication among recommended proposals and to assign each proposal an observational priority rank.

Observations selected from the first call for proposals in 1989 are scheduled for execution during ROSAT's first pointed phase. A second call for proposals will be announced at a later date. While the nominal ROSAT mission lifetime is 2 years, the satellite is expected to remain operational for a much longer period. New observing proposals will be sought periodically.

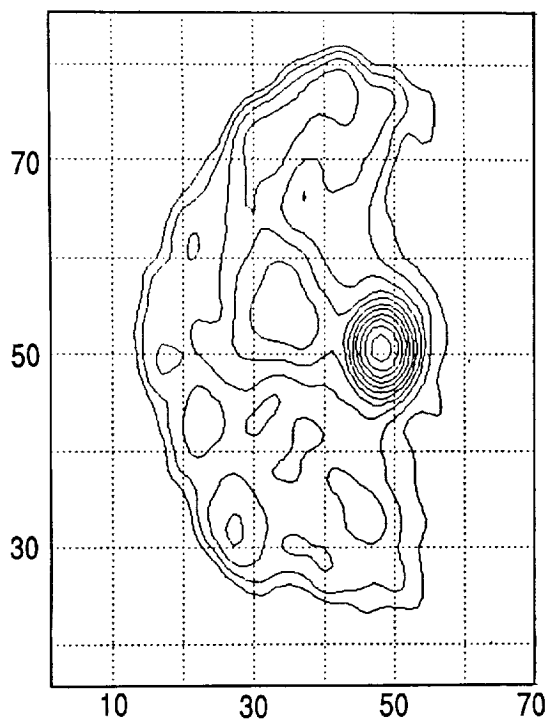
ROSAT will be pointed at selected individual X-Ray sources for varying

lengths of time, depending upon the intensity of each source. An hour or more of observing time may be required to obtain sufficient data for analysis of a particular X-ray source. Observations of the faintest sources will require sustained pointing of the spacecraft at a given target over several orbits.

Data are processed initially at the German Space Operations Center, in Oberpfaffenhofen, Federal Republic of Germany. Magnetic tapes containing master data records are shipped to the US ROSAT Science Data Center (RSDC) at NASA's Goddard Space Flight Center in Greenbelt, Maryland. The ROSAT Standard Analysis Software System (SASS), developed by MPE and the Harvard-Smithsonian Center for Astrophysics (CfA), is used to yield a standard data product for each observation. Following verification and SASS processing at CfA, the data are released to original investigators and archived in the Goddard RSDC. Data are treated as proprietary for the origi-

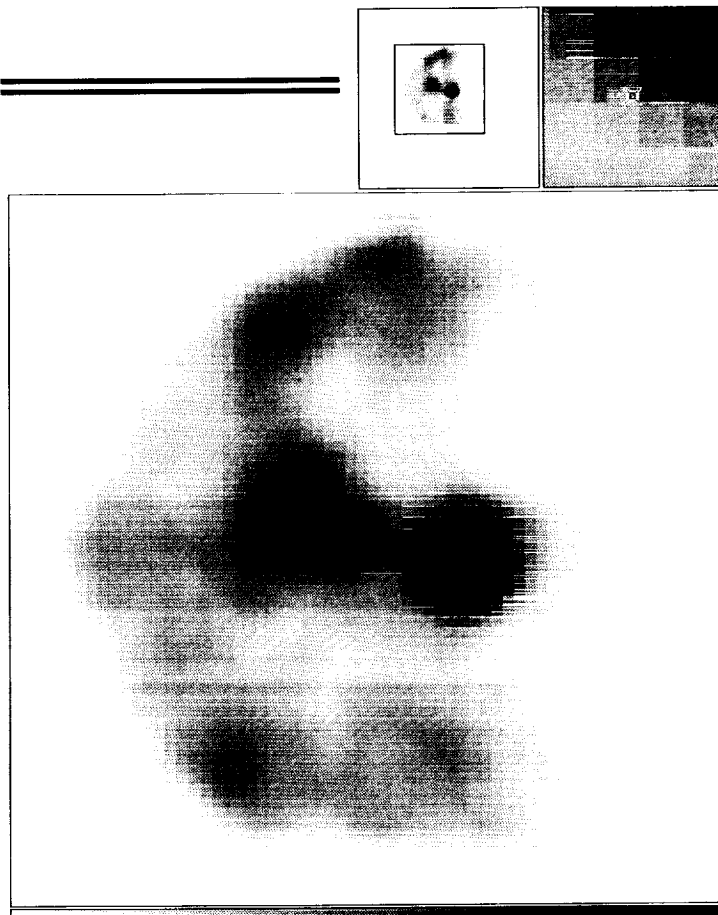


The above plots were made using the PROS computer software. The plot on the left shows the pulsation frequency of the pulsar in supernova remnant CTB109 as determined by the timing analysis package. Spectral modeling is also available with the software. On the right, the raw X-ray counts for the remnant are compared to a theoretical model.



CTB 109. Einstein IPC sequence 8102
demo_center_smo . imh (20:120.20:120)

	Contour Levels:
Field Center:	111.049
22 ^h 58 ^m 56 ^s	76.791
+58°36'47"	53.101
	36.720
	25.392
	17.558
	12.142
X Scale: 0.63 pix/m	8.396
Y Scale: 0.63 pix/m	5.806
	4.015
	2.776



The contour plot on the left, a smoothed image of the supernova remnant CTB 109, was produced using the PROS spatial analysis package. The software also allows a guest observer to create a gray-scale image, like this one on the right of CTB 109, to which color has been added.

nal investigators for 1 year from the date of receipt, after which they become generally accessible.

The United States is providing extensive assistance to its ROSAT Guest Observers. Two Guest Observer facilities have been developed: at the NASA Goddard Laboratory for High-Energy Astrophysics in Greenbelt, Maryland, and at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts.

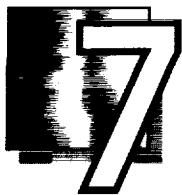
As part of the RSDC activities, the CfA has developed a standard set of software packages for scientific analysis. They are transportable and run under the Image Reduction and Analysis Facility (IRAF*). IRAF is a product of the National Optical Astronomy Observa-

tories and is already a familiar tool to many astronomers. Using this new package, called "PROS" (for Post Reduction Off-Line Software), observers can extract and display photon counts, smooth their data, perform analysis of X-ray spectra and light curves (graphs showing a source's changes in brightness over time), as well as perform other modeling. Because PROS is compatible with the widely used IRAF, it facilitates spectral studies and comparisons of X-ray data with data collected at other wavelengths for the same object.

An on-line computer service for information retrieval is also being offered by the US ROSAT Science Data Center. The Mission Information and Planning System (MIPS) will provide readily

accessible data to help potential ROSAT users plan their observing proposals. With it, a prospective observer can calculate observing time and viewing windows, and can access a technical data base providing performance specifications of the ROSAT X-ray instruments and existing information on the source. The system also contains a bulletin board and mail facility where present observers and prospective proposers will find information on the Guest Observer program, the status of observations and data processing, and items of general interest.

** IRAF is distributed by the National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc. under contract to the National Science Foundation.*



ROSAT MILESTONES

1975: Max Planck Institute for Extraterrestrial Physics (MPE) proposed ROSAT as a German national space program to the Federal Ministry for Research and Technology (Bundesministerium für Forschung und Technologie, BMFT)

1982: NASA and BMFT signed memorandum of understanding establishing cooperation between United States and Federal Republic of Germany (FRG) on ROSAT, including launch from Space Shuttle in 1987

1983: BMFT and British Science and Engineering Research Council (SERC) signed memorandum of

understanding establishing FRG-United Kingdom (UK) cooperation on ROSAT

1987: NASA/BMFT decision to launch ROSAT on a Delta-II launch vehicle, rather than the Space Shuttle

Feb 1989: First Research Announcement released soliciting proposals for pointed observations

May 1989: US, FRG, and the UK received a total of 717 proposals

Oct 1989: Telescope and flight instruments calibrated

Oct 1989: ROSAT pre-ship review held in FRG

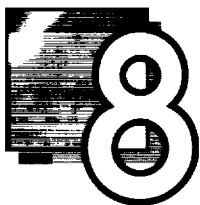
Oct 1989: Meeting of International Users Committee to resolve conflicts in the recommended national proposal selections

Feb 1990: ROSAT shipped to Cape Canaveral Air Force Station, Florida

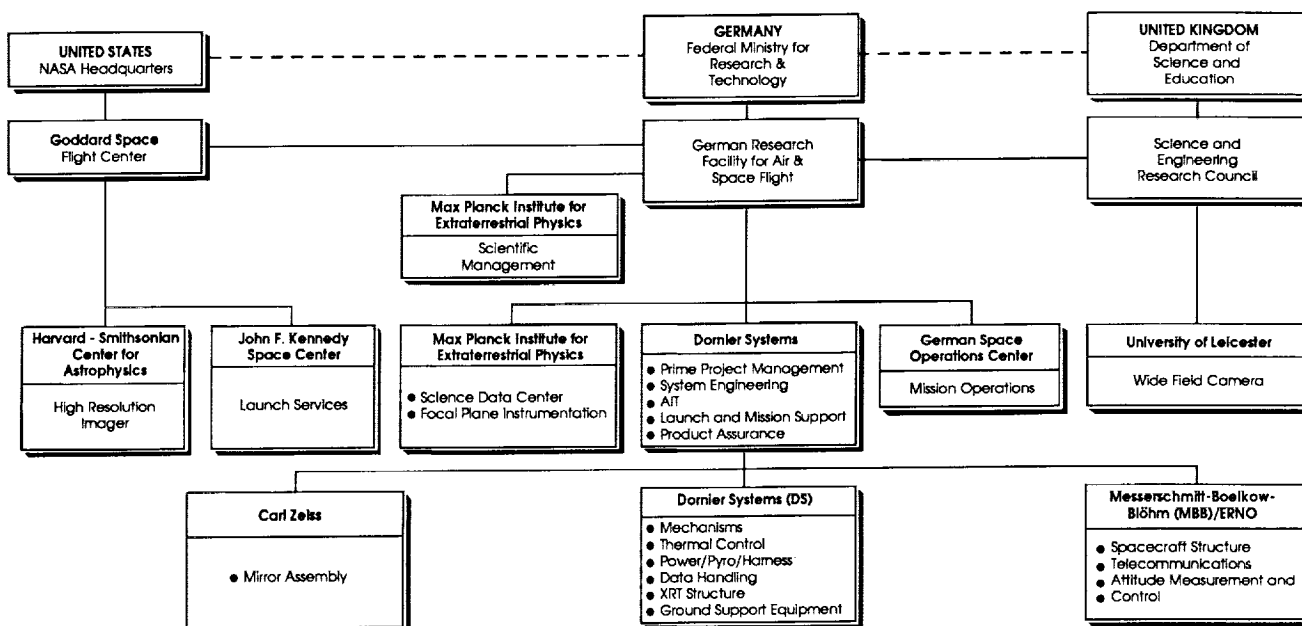
June 1, 1990: ROSAT launched

July 29, 1990: Observatory checkout completed; all-sky survey begun

Launch + 8 months: Begin pointed phase of mission. Pointed observations will continue throughout the mission, which is expected to last at least until January 1992



ORGANIZATION



Technical Glossary

arc second

60 arc seconds = 1 arc minute, 60 arc minutes = 1° on the circumference of a circle

cascade configuration

an arrangement of devices connected in a series so that they multiply the effect of each device

electron Volt (eV)

a general unit of energy for fundamental particles and electromagnetic radiation

extragalactic

beyond the Milky Way Galaxy

flux

quantity flowing across a given area

isotropic

quality of having the same intensity in all directions

Kelvin

the standard international unit of absolute temperature

luminosity

the intrinsic energy output of a star

magnetometer

instrument for measuring intensity of a magnetic field

microchannel plates

plates that consist of extremely small cylinder-shaped electron multipliers mounted side by side to provide image intensification

plasma

a high-temperature ionized gas

progenitor star

the star responsible for an outburst or supernova

protostar

a star in the process of forming

spatial resolution

capability to distinguish separate radiation sources that appear close together

spectral resolution

the capability to resolve detailed features in the spectrum of a source

starburst galaxy

galaxy with a high rate of new star formation

telemetry

transmission of instrument readings to a remote location

torquing device

on ROSAT, a device that uses the Earth's magnetic field to maintain stability

Small Magellanic Cloud

one of two small irregular galaxies close to the Milky Way Galaxy, known as the Large and Small Magellanic Clouds; visible in the Southern skies.

X-ray burster

object in space repeatedly producing sudden, intense bursts of X-rays, typically lasting only a few seconds.

The US ROSAT Team

Dr. Lennard A. Fisk, Associate Administrator, Office of Space Science and Applications, NASA Headquarters

Alphonso V. Diaz, Deputy Associate Administrator, Office of Space Science and Applications, NASA Headquarters

Dr. Charles J. Pellerin, Jr., Director, Astrophysics Division, Office of Space Science and Applications, NASA Headquarters

John A. Lintott, ROSAT Program Development Manager, Astrophysics Division, NASA Headquarters

Dr. Guenter Riegler, ROSAT Program Operations Manager, Astrophysics Division, NASA Headquarters

Dr. Alan N. Bunner, ROSAT Program Scientist, Astrophysics Division, NASA Headquarters

Dr. Louis Kaluzienski, Deputy Program Scientist, Astrophysics Division, NASA Headquarters

Dr. John W. Townsend, Jr., formerly Director, NASA Goddard Space Flight Center

Gilbert W. Ousley, Sr., ROSAT Project Manager, NASA Goddard Space Flight Center

Dr. Stephen S. Holt, ROSAT Project Scientist, NASA Goddard Space Flight Center

Dr. Robert Petre, Deputy ROSAT Project Scientist, NASA Goddard Space Flight Center

Dr. Robert Price, Director, ROSAT Science Data Center, NASA Goddard Space Flight Center

John Gerdes, HRI Project Manager, Harvard-Smithsonian Center for Astrophysics

Dr. Martin Zombeck, HRI Project Scientist, Harvard-Smithsonian Center for Astrophysics

Dr. Stephen S. Murray, Data Analysis Center Manager, Harvard-Smithsonian Center for Astrophysics

Acknowledgments

Within NASA, ROSAT is managed by the Astrophysics Division of the Office of Space Science and Applications. The detailed implementation of the US ROSAT Program is under the management of the Goddard Space Flight Center. The Goddard Flight Projects Directorate, ROSAT Project Office, provides overall United States project management and the Space and Earth Sciences Directorate is providing the Project Scientist and ROSAT Science Data Centers. The Flight Projects Directorate, Orbital Launch Services Office, also provided NASA field center management of the Delta-II launch vehicle.

The ROSAT telescope was designed and developed by Germany's Max Planck Institute for Extraterrestrial Physics (MPE) and the Carl Zeiss Corporation, under the direction of Professor Joachim Trümper. The spacecraft was built at Dornier GmbH, also of Germany. The Position-Sensitive Proportional Counters were provided by MPE. From the United States, the High-Resolution Imager was provided by the Harvard-Smithsonian Center for Astrophysics, under the direction of Drs. Harvey Tananbaum, Stephen S. Murray, and Martin Zombeck. From the United Kingdom, the Wide-Field Camera was provided by a consortium of the University of Leicester, Rutherford-Appleton Laboratories, and Mullard Space Science Laboratory under the direction of Professor Kenneth Pounds.

Brochure Preparation

Manager, Patricia Pengra, BDM International, Inc.; Editor, Marilyn Finley, BDM International, Inc.; Graphic Artist, Jeff Lilly, BDM International, Inc.

Contributors:

Dr. Keith Arnaud, Goddard Space Flight Center/University of Maryland; Dr. Alan Bunner, NASA ROSAT Program Scientist; Dr. Cynthia Cheung, BDM International, Inc.; Dr. Jim Heppner, BDM International, Inc.; Dr. Jack Hughes, Harvard-Smithsonian Center for Astrophysics; Dr. Louis Kaluzienski, NASA ROSAT Deputy Program Scientist; Mr. John Lintott, NASA ROSAT Program Manager; Dr. Albert Opp, BDM, International, Inc.; Dr. Eric Schlegel, Goddard Space Flight Center/Universities Space Research Association; Dr. T. Jane Turner, Goddard Space Flight Center/Universities Space Research Association.

Credits

Cover: Puppis A, Einstein Observatory, courtesy of Harvard-Smithsonian Center for Astrophysics.

Overview: ROSAT, Artist's illustration.

Table of Contents: Eta Carinae in X rays, Einstein Observatory, courtesy of Harvard-Smithsonian Center for Astrophysics; Eta Carinae optical, courtesy of National Optical Astronomy Observatories.

Page 1: Wilhelm Conrad Roentgen, Deutsches Museum, Munich.

Page 2: Artist's illustration of the electromagnetic spectrum.

Page 3: HEAO-1 all-sky map, courtesy of US Naval Research Laboratory.

Page 4: Artist's illustration of ROSAT as an evolutionary step to NASA's "Great Observatory" AXAF.

Page 5: Solar corona, courtesy of Harvard-Smithsonian Center for Astrophysics.

Page 6: SNR E102.2-72 in X rays, Einstein Observatory, courtesy of Harvard-Smithsonian Center for Astrophysics; optical image, taken at Cerro Tololo Inter-American Observatory in Chile, courtesy of the Association of Universities for Research in Astronomy, Inc.

Page 7: M51 in optical light, official US Naval Observatory photograph; M51 in X rays, Einstein Observatory, courtesy of Harvard-Smithsonian Center for Astrophysics; M87, optical, courtesy of National Optical Astronomy Observatories; M87, in X ray, Einstein Observatory, Harvard-Smithsonian Center for Astrophysics.

Page 8: Clusters of galaxies in X rays, Einstein Observatory, courtesy of Harvard-Smithsonian Center for Astrophysics.

Page 9: Exploded view of Delta-II launch vehicle.

Page 10: ROSAT atop a Delta-II launch vehicle, both photographs courtesy of NASA.

Page 11: Artist's illustration of ROSAT orbit.

Page 12: Exploded view of ROSAT key elements, courtesy of Dornier GmbH.

Page 13: High-Resolution Imager, courtesy of Harvard-Smithsonian Center for Astrophysics (CFA); HRI diagram, Goddard Space Flight Center; cross section of X-ray telescope, based on diagram courtesy of Max Planck Institute for Extraterrestrial Physics.

Page 14: Flight model of ROSAT, courtesy of Dornier GmbH.

Page 15: Imagery from ROSAT, courtesy of BMFT and MPE.

Pages 16 and 17: Computer-generated graphs, courtesy of NASA Goddard Space Flight Center.

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Administration